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Abstract — The Thai rice seed system is undergoing an important reform. In this context, we organised a series of participatory modelling sessions with stakeholders to elicitate farmers' needs and decision making processes concerning rice varieties and seeds supply in Ubon Ratchathani province. A conceptual model in UML diagrams was produced and partly implemented as an ABM.

The ABM models on a yearly time step the requirements and the allocation of seeds for the two main varieties between farmers and public or private institutions at village, district, and provincial levels.

A prototype model was presented and discussed with representatives of the main institutions concerned by the current reform. After this validation by users, they proposed possible future scenarios to be simulated and assessed with them.

Key words : Seed system, rainfed lowland rice, participatory modelling, agent-based model, Northeast Thailand.

Résumé — D'imporantes réformes sont en cours dans le système semencier thailandais. Dans ce contexte, une série d'atelier de modélisation participative ont été organisée avec les acteurs du système pour éliciter les besoins et les processus de décision concernant les variétés de riz et l'approvisionnement en semences dans la province d'Ubon Ratchatani. Un modèle conceptuel UML a été produit et partiellement implémenté dans un modèle multi-agent.

Le modèle multi-agent permet de simuler sur un pas de temps les besoins et l'allocation des semences des deux principales variétés de riz par les institution publiques, privées ou coopératives au niveau des villages, des districts et des provinces.

Un prototype a été présenté et discuté avec les représentants des institutions principales concernées par la réforme en cours. Après cette validation par les usagers, des scénarios possibles ont été proposés pour être simulés avec le modèle multi-agents et discutés.

Mots clés : système semencier, riz de bas fond, modélisation participative, modèle multi-agent, Nord-Est Thaïlande

INTRODUCTION

The northeastern region of Thailand has the largest area planted to rice in the kingdom and produces more than one third of the total national output. But 85% of the 5.2 million ha of rice in this region are cultivated under rainfed conditions, with a single crop per year. The low physical productivity (average paddy yield is 1.8 t ha^{-1}) of the paddies is mainly due to the combined effects of low water-holding and infertile coarse-textured soils, erratic rainfall distribution (1200 mm/year mainly from May to October) and low input use (Jintrawet, 1995; Somrith, 1997). But for more than 7 millions farm workers living in this most populated region of the kingdom (21 millions out of a national total of 65 millions, regional population density of 126 inhabitants/km^2), small-scale RLR farming has been a way of living for centuries with an average size of land holding of 3.2 ha (OAE, 2007). Rice is the staple food crop of both dominating Lao Issan (who eat glutinous rice, mainly RD6 variety) and Khmer (who eat non glutinous rice, mainly KDML105 variety) people who live mainly in the lower sub-region where paddies cover some 80% of the area. Rice is grown on undulating land made of adjacent mini catchments composed of well-drained upper, medium and flood-prone lower paddies that are usually planted to different RLR varieties with different duration cycles. RLR is also a major economic crop because of the local production of renowned strains of aromatic rices that find their way to international markets. Paddy sales could represent some 20% of the households total cash income. Under very constraining soil-water conditions, the grain quality of these aromatic jasmine cultivars is the main comparative advantage allowing to secure higher farm gate price for paddy that partly compensate the average low yields and single crop per year. Seed quality is important to maximize this comparative advantage.

In this farming context, RLR varietal and seed management is complex and involves decisions on varietal choice, desired degree of agrobiodiversity, and the procurement of good quality seed. In recent years, facing the inadequate supply of good quality seed of dominant RLR varieties, the Thai rice seed system (RSS) has been undergoing profound changes, especially the entry of different types of private seed producers (from large private companies like the CP Group to village level Community Seed Centers), and the subsequent increased adoption of a few recommended varieties (particularly KDML105, RD6 and the shorter duration non glutinous RD15) replacing hundreds of traditional cultivars exchanged among farmers. A growing number of diverse stakeholders interact in the RSS without knowing each other or coordinating their operations, and each of them having only a very incomplete understanding of how the whole system operates.

The main objective of this study was to test the use of participatory modelling to build a shared representation of rice varietal and seed management at the provincial scale with the main concerned stakeholders (different types of rice growers, extension agencies, cooperatives, public and private seed suppliers, and community seed production centres) in the major RLR producing province of Ubon Ratchathani in lower northeast Thailand. Based of this better understanding of the local RSS, the second objective was to implement this shared representation of the RSS into an agent-based model (ABM) used as a simulator to explore different possible future scenarios identified by the main stakeholders and to assess the ability of the RSS to meet farmers' demand and to adapt to its unpredictability under those different circumstances (Vejpas et al. 2005). In this paper, following a short presentation of the participatory modelling methodology and tools used in this case study, the emphasis is on the description of the ABM co-designed with the local actors and its use to simulate scenarios. The paper ends with a discussion of the results and a presentation of the future perspectives.

1. MATERIAL AND METHODS

The so-called Companion Modelling (ComMod, www.commod.org) approach was used to facilitate the dialogue among the RSS stakeholders and the exchange of knowledge and points of view about the seed system because it is a proven methodology to set-up and manage inclusive, open, and highly interactive collaborative modelling processes (Bousquet & Trebuil, 2005). ComMod processes are iterative but evolving and rely on different kinds of models (conceptual, role-playing games, agent-based ones) to stimulate the interactions among stakeholders. These models are co-designed, validated, played or simulated with stakeholders and evolve according to their changing needs following the acquisition of new knowledge or change in the context.

The main phases of the implemented ComMod process were as follows:

- A preliminary sample description survey at the farm level was carried at the provincial level, among 258 farmers in 25 districts, to gather baseline data on the spatial, quantitative, and qualitative distribution of farmers' needs of rice seed in every district of Ubon Ratchathani province. In particular, it provided a picture of the heterogeneity of farmer' situations regarding access to seed suppliers, the districts located in the northern part of the province having a more diverse choice compared to the more remote southern ones. Representatives of key organizations involved in the RLR see system were also interviewed to provide information of the activities of different kinds of seed suppliers and to sensitize them to participate in the ComMod process.

- Short workshops with selected seed producers: To understand the rice seed system structure and functioning at the provincial scale, a series of meetings were organized with representatives of the main seed producing organizations. For most of them, it was the first opportunity to meet and discuss the RSS issue. During these meetings, a conceptual model of the seed system was built based on the knowledge provided by the participants. This knowledge base was displayed on the screen as a set of Unified Modelling Language (UML) class and activity diagrams to be gradually enriched and validated by them. After several sessions, an agreement on the structure and functioning of the provincial RSS was reached (Vejpas *et al.* 2005).

- In the next phase, this conceptual model was translated into two complementary role-playing games:

(i) the fist one was used with farmers at different locations (according to a gradient of remoteness of their villages to seed suppliers) to validate the research team understanding of the generation of the demand for seeds at the village level. This gaming and simulation tool allowed to better understand the farmers' decision-making processes dealing with the selection and allocation of a combination of RLR varieties in their paddies, their seed management practices, and choice of seed suppliers.

(ii) the second gaming tool simulated the production and provision of seeds in a virtual province by various suppliers operating at the village, sub-district, district or whole province levels. These participatory modelling and simulation sessions were used to elucidate seed supplier practices, decision-making processes and interactions. This activity was instrumental in the validation of the conceptual model representing the relationships (or lack of) among the RSS stakeholders and the flow of different types of (foundation, stock and certified) seeds among them (Vejpas *et al.* 2005).

- Finally an autonomous Agent-Based Model (ABM) was built.

This ABM implemented under the CORMAS platform simulates the seed requirements from farmers and the allocation of seed from public and private suppliers to meet the demand for certified seeds of the two most popular glutinous (RD6) and non glutinous (KDML 105) rice varieties and is described extensively in the following section. It implements the conceptual models developed in the previous phases and runs simulations on a yearly time step and at the village, district, and provincial levels.

The ABM was instanciated on the specific case of the virtual province used during the second gaming workshops and presented to key stakeholders during a series of meetings and demos in their offices. The features and operating rules of the simulator were explained and discussed with representatives from the main seed suppliers to improve and gradually validate them. More particularly, the decision making rules concerning seeds quantity planning and allocation priorities were

The potential use of this simulator to help manage the current reform of the RSS (favouring a growing role for the private seed suppliers, especially the community seed centres) was also discussed. These potential users proposed possible future scenarios of interest to be simulated and assessed for such a purpose.

2. RESULTS

2. 1 The Conceptual models

The representation of the seed consumption (at the farm and village levels) and seed supply (from the village community to the provincial level - and even the national level regarding the provision of foundation seeds) systems are described elsewhere (Vejpas *et al.* 2005), but key findings from the conceptual modelling and role-playing game workshops are summarized in figures 1 and 2 showing the decision model for the choice of seed sources and suppliers at the farm level and the seed supply system at the provincial scale respectively.

This conceptual model was used as a base for designing the initial version of the Agent-Based model. Whereas focus of the first phase of conceptual modelling and role-playing game was on the provincial seeds system as well as on the farmers scale, in this phase the focus was brought exclusively on the provincial seeds system. As a consequence, contract farmers and detailed farmers behaviors were not considered in this phase which focused on provincial seeds system flows and decision making. . A prototype was then use to hold workshops with the stakeholders where they discussed, refined and corrected the hypotheses displayed through the demonstration of the prototype. The result can be seen on figure 3. The diagram on the left is equivalent to the UML diagram of figure 2. The diagram on the right is the conceptual model such as it is implemented in the ABM : priorities and specification in seeds flows are specified, as well as the status of the stakeholders.

2.2 The Agent-Based Model

The way these multi-level models were merged into a single ABM integrating all the relevant scales of seed consumption, production and distribution is shown.

2.2.1 Overview

This ABM represents the Rainfall Lowland Rice (RLR) seeds system of North-East Thailand at the provincial scale. Only “active” stakeholders are represented (the fact that the decisions are taken by Bangkok institutions is not represented). Agents are RLR seeds system stakeholders that act from the Province level to the Farm level and that might have preferential relations between each others. These agents exchange and/or multiply seeds stocks from 2 varieties: a glutinous (RD6) and a non glutinous one (KDML105).

These agents hold roles in the seeds supply chain. They might be seed producers, middlemen or rice growers, respectively to each variety. These roles are connected through provider and customer links ranked with priorities. These links and their priorities depend on which stakeholder they are held by.
One time step represents one year and reproduces the phases of one time step of the RPG : planning of needed quantities and orders, production or multiplication of seeds in stock from last year, treatment of orders and direct requests, seeds provision to farmers. From one year to the other, seeds production is adjusted on previous years and farmers demand is adjusted on paddy market prices. Seeds prices are not considered in the model as it was not considered as a determinant parameter for seeds supplier choice. The number of multiplication and origin of seeds is traced but only used marginally.
The model can be described abstractly as follows: A resource is exchanged among a supply chain from producers to consumers. Consumption and production of the resource can happen only once a year. 1 producer only is able to produce a high quality resource in small quantities. Other producers multiply the resource they manage to get from the supply chain. Each time the resource is multiplied, its quality decreases. All stakeholders in the supply chain have preferences among their providers and customers. Each time step happens as following : 1. Planning: customers plan their demand and stakeholders establish their needs 2. Resource production 3. Resource supply : the resource is distributed accross the supply chain up to the customers 4. Assesment : customers assess supply and may change supplier

2.2.2. Entities and scales

2.2.2.1 Biophysical Entities

Seeds entity represents seeds stocks that circulate between the stakeholders. A seeds stock is described by :

- a *quantity*, given in tons
- a *variety.* 2 varieties are available in the model : KDML (aromatic) and RD6 (glutinous). It is the 2 main RLR varieties that are recommended and produced by RRC.
- a *quality* : FS (Foundation – produced from breeder seeds in RRC), SS (Stock – produced from FS), CS (Certified – produced from SS), or NC (non certified, produced from CS)
- a *source* : the list of all its multipliers
- an *age* : the number of years since its last multiplication

2.2.2.2. Space

The space represents an archetypal province with its administrative areas represented by aggregates. All aggregate spatial entities are *AdministrativeArea.* Each Cell belongs to a *Tambon*, that belong to an *Amphoe*, that belong to a *Province*.
Amphoe are also characterized by their *accessibility*. In *normal* amphoes, farmers and farmers communities have access to the provincial public seeds producers (RRC and SC). In *remote* amphoes, a part of seeds renewal is done through informal exchanges between farmers.

2.2.2.3. Socio-economics

The international rice market is roughly represented by a *Market* agent that fixes paddy prices. It is characterized by the up and down limit of paddy prices.
Farmer individuals are represented by *Farmer* agents. In each tambon, their individual needs generate a global seeds demand. A *Farmer* updates his needs each year considering the proportion of rice varieties on its plots and whether he renews its seeds or not. This demand is attributed to a supplier. This supplier is attributed by initial conditions but it may change according to the farmer experience.
Stakeholder is the generic entity representing the seed system stakeholders. These stakeholders are :

- *RRC* : Provincial Rice Research Center. Provides FS within the province to *SC* and seeds producing *AC*. Also provides seeds to *CSC* and *ST* from non remote amphoes. SC and seeds producing AC are registered customers for RRC.
- *SC* : Seeds Center. Public SS multiplier (province level). Provides SS to *DAO*, *ST*, *BA* and grown up *CSC*.
- *BA* : Bank of Agriculture. Private SS trader (province level).
- *AC* : Agricultural Cooperative. Farmers organisation SS multiplier and trader (amphoe level). Not all *AC* produce seeds. The seeds producing *AC* provide seeds to seeds non-producing *AC*. All *AC* provide seeds to *ST* and grown up *CSC*. *AC* can always satisfy farmers demand through networking.
- *ST* : Seed Traders. Private seeds traders (amphoe level). Provides seeds to *BA*
- *DAO* : District Agricultural Office. Agricultural extension, used to be official public seeds distributor (amphoe level). Provides seeds to young *CSC.* Young CSC and farmers are registered customers for DAO.
- *CSC* : Community Seeds Center. Seeds production farmers community structures (tambon level). CSC are also characterized by their *age.* After 4 years, CSC status is changing.
- *TambonFarmers* : virtual entity aggregating demand and seeds distribution for the farmers of one Tambon. TambonFarmers defines *n*, the number of farmers in the tambon, as well as *providersDistr* which is the repartition of providers share within one tambon. Can get seeds from any stakeholder but *RRC.* In remote amphoes, no acces to *SC*.

2.2.2.4. Supply Chain Roles

5 different roles in the seeds supply chain have been identified. These roles define the behaviors of the stakeholders in the seeds systems within the various supply chain processes. (needs planning, seeds production or multiplication, seeds supply, seeds use). These roles are :

- FSProducer : produces FS according to estimate needs and limiting capacity; supply FS to customers. Held by RRC
- Multipliers : purchase FS or SS from providers, multiplies into SS or CS, supply production to customers. Held by SC, CSC, producing AC
- MiddleMen : purchase seeds from providers, supply it to customers. Held by ST, BA, non producing AC and DAO.
- RiceGrowers: purchase seeds from providers and use it for paddy. Held by TambonFarmers

Supply Chain Roles are characterized by :

- a *variety* they deal with. A stakeholder should have as many roles as varieties he is dealing with
- *providers* and *customers* ranked with priorities. Links are set up according to stakeholders and priorities are set up according to rules discussed with stakeholders and displayed in the parameters table in the appendix.

2.2.2.5. Time Scales

The time step is 1 year for all entities. The year is separated in different phases (planning, production, distribution, estimation) where the entities may or may not act depending on their roles.

As stakeholders planning have to adjust on sales from an arbitrary initial value, a simulation is initialised first with a “blank” 20 years run so that the system gets to an equilibrium through stakeholders adjustments.

2.2.2.4. Spatial Scales

The smaller spatial unit is the tambon (sub-district) and the grid represents a province. There is an intermediary administrative area : the Amphoe.

Every stakeholder distributes seeds within an administrative area : *CSC* acts at the tambon level. At this level, *TambonFarmers* aggregates demand and provision for the tambon farmers. *Farmer* individuals are only used to set up the demand within a tambon and get seeds from a specific supplier, they are not linked to specific cells. *AC*, *ST* and *DAO* act at the Amphoe level. *RRC*, *SC* and *BA* act at the Province level

2.2.3 Processes and Scheduling

2.2.3.1. Biophysical Processes

The only biophysical processes in the model are held by *FSProducer* and *Multiplier* agents and concern **seeds production and multiplication**. They consist in applying a stochastic hazard on expected seeds production or multiplication values. Resulting seeds are put in their *distributionStock.*

2.2.3.2. Socio-economical processes

Paddy price evolution (Market) has been asserted as unpredictable: it consists in a series of randomly drawn values between the lower and upper limits identified with the stakeholders.

Farmers' seeds demand is calculated each year individually for each farmer. It depends on previous years seeds provision in that farmers demand for seeds when they get too old according to its own criterion (a fixed frequency) and renew their demand every year until it is satisfied. However the demand may be satisfied by informal exchanges. In consequence, a farmer's seeds demand results from his rice growing area, its seeds age, its seeds replacement frequency, its propensity to get seeds from other farmers, and its varieties distribution. Depending on market prices, farmers may raise their proportion of KDML and renew more seeds.

Farmers' supplier choice. Farmers may decide to get a new supplier when their current supplier does not succeed in delivering seeds, or delivers seeds which have been multiplied too much or coming from outside the system[1]. There is a fixed set of suppliers that can be accessed by all the farmers within a tambon. We have chosen to implement the simplest possible set of hypotheses to represent the choice of a new supplier. This set of hypotheses is realistic enough and allows to test the dynamicity of the model but it would need to be refined to represent realistic dynamics. These hypotheses are : (1) seeds price has no impact on supplier choice (2) farmers assess their supplier on their reliability in answering a demand with adequate seeds (which have not been multiplied too much or coming from outside the system) (3) farmers assessment of a supplier is cumulative all along his life and a good assessment increases the chance to be chosen again (4) even with a bad assessment, it is always possible that a farmer choose a supplier again.

Seeds supply planning is performed by all supply chain actors and consists in making previsions on customers demand every beginning of year: the planned quantity is the objective quantity to get its distribution stock. There is 2 way of planning in the model : collecting information about customers needs and adjusting the prevision on this information (**order based planning**) or adjusting the prevision on previous years actual sales (**adjusted planning**). RRC and DAO have registered customers and practise order based planning. All the other one do not collect orders and adjust to previous sales. The depth of memory used can be adjusted.

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[1] This is quite an artificial hypothesis that was introduced on the one hand to test how farmers could use quality appreciation to modify their suppliers choice, and on the other hand to balance the AC success in always providing seeds by getting seeds fro outside the province through its network

Seeds purchase is performed by all supply chain actors except *FSProducer.* It consists in sending a direct request to a provider in order to get the planned quantity of seeds.
For *Muliplier* and *MiddleMen* agents, direct requests are sent to providers one after each other, following their priority ranking for the whole needed quantity of seeds, until this quantity has been purchased or the providers list is over. The offer of a provider is always accepted, and its answer is needed before sending the next direct request. *Multiplier* agents put received seeds in their *productionStock, MiddleMen* agents put received seeds in their *distributionStock.*
When it has completed its purchase, SC checks its *productionStock*. If plannedQuantity is not reached it transfers the needed quantity from its *distributionStock* to its *productionStock.*
For *RiceGrower*, the quantity of seeds to purchase is determined by the aggregated Farmers' seeds demand. If a supplier does not provide enough seed, farmers randomly drawn among its suppliers do not get seeds.

Seeds distribution is performed by all supply chain actors except *RiceGrower*. At the end of a "distribution round", the received direct requests are treated. If there is enough seeds in the *distributionStock* to satisfy all the direct requests, all the direct requests are answered with the requested seeds quantity. If not, the seeds are distributed using weights according to *buyers_priorities* so that higher priority buyers get more seeds but that nobody gets nothing. If different qualities of seeds are available, best quality are given first.

2.2.3.3. Description of scheduling

One time step is scheduled as followed:

1. Step initialisation : surplus stocks are destroyed : distribution stocks are set to 0
2. Planning : Paddy price evolves with market; farmers set their demand; stakeholders plan their objectives recursively (the top producer asks their plans to all its customers who ask their plans to all their customers and so on until end customers. When a provider has received the answers from all its customers, it operates its planning (either order-based or adjusted) and answers all its providers and so on).
3. Seeds production and multiplication. In multiplication, *productionStocks* from previous year are used
4. Seeds distribution and purchase : distribution and purchase functions of the agents are scheduled within a distribution protocol. This protocol consists of 4 sessions where some agents act as customers (purchase function) and other as provider (distribution function). Each session consists of several rounds. During each round :
   a. Customers sends their request (first part of the purchase function)
   b. providers treat the requests (distribution function)
   c. Customers receive the seeds according to the answers from the providers (last part of the distribution function)

   New rounds are launched until all customers have not received the seeds they wanted or have not browsed their whole providers list. Then the session ends. The 3 sessions are populated as follow:

   d. RRC answers orders : customers = (producing AC, SC); providers = (RRC) - (producing AC and SC fill their multiplication stocks for next year
   e. everybody but SC and RRC request seeds : customers = (AC, ST, DAO, CSC, BA); providers = (RRC, SC, AC, ST, BA)
   f. DAO answers orders : customers = (TambonFarmers, CSC); providers = (DAO)
   g. TambonFarmers receive seeds from everybody except DAO : customers = (TambonFarmers); providers = (AC, ST, CSC, BA, SC, RRC)

   The way these sessions are populated and sequences has been quite a delicate parameter of the model : it may greatly influence the simulation results and can only be a very rough approximation of the real seeds market sequencement. We've considered different possibilities but after a few sensitivity analysis, we've decided to use a slight enhancement of the sequencement represented during the game, which had already been validated by the stakeholder. The only difference with the game is that traders are second-order providers (they can provide seeds to other providers) and that some CSC may be provided by DAO, as we learnt during ABM sessions.

5. Assesment : farmers assess their suppliers and possibly choose a new one for the following year.

2.3 The prototype and the workshops

2.3.1. Workshops progress and ABM interface elements for interacting with the stakeholders

The workshops were designed so that the ABM demonstration could be used as a restitution support of our understanding of the system. The model structure and dynamics was explained step by step through the different viewpoints provided by the CORMAS interface. Special emphasis was put on data and hypothesis concerning the agents that represents the stakeholders attending the workshop. The stakeholders could react and complete or correct the model all along the demonstration. Then a debriefing was held in order to define what are the stakeholders expecting from the model.

Providers and customers lists and priority levels can be modified at any time of the simulation through a dedicated interface. The procedure used during the demonstration was the following: the spatial elements of the interface are presented and explained; the different agents are shown within the territory they supply: are all the stakeholders represented? Is their spatial allocation right? ; for each agent, the supplying and buying links are shown: are all the links correct? Is there some links missing? Are the priorities right?; the simulation is run for a year step by step, showing the information and seeds exchange between the agents; simulation results figured as histograms are shown for a few years (figures 4 and 5).

The model structure description was very efficient in definitively validating the stakeholders roles and relations. The histograms were very efficient in getting back on the hypothesis we made on agents decision-making about seeds distribution.

2.3.2. Workshops main results

The workshops were very efficient in getting information gaps filled. In particular, the following elements of the model were extracted and validated from the workshops : validation and completion of stakeholder links and priorities, definition of the institutional status, impact of tambons remoteness, refinement of the seeds allocation function, hypotheses on farmers demand evolution with paddy market price, definitive choice of varieties, AC networks.

5 potential scenarios that could be explored with the ABM simulations were also defined :

- baseline scenario, in the current state of the model
- institutional reform : merging of RRC and SC. This scenario is translated in the model by RRC providing seeds only to SC
- decentralisation : number of CSC increases with institutional reform. This scenario is translated in the model by creating 1 CSC in each tambon.
- modernisation : all farmers get mechanized and renew their seeds every year
- decentralisation + modernisation

2.4 Simulation results

The 5 scenarios were simulated with an identical random paddy price series and with and without farmers being able to change supplier.

The model is always more efficient in delivering seeds to farmers without generating too much surplus when farmers are not able to change suppliers. The main reason is certainly that as one hypothesis being that farmers tend to prefer suppliers who deliver only province grew certified seeds, there are less farmers getting their seeds from AC which is giving a 100% success in the cases where suppliers are not fixed. There is no subsequent difference in the different scenarios, except the ones with modernisation where the demands are answered more efficiently. This is due to the fact that even if the demands are increasing,

they are more stable, which makes the seed system stakeholders able to predict is correctly and answer it (figure 6).
It can be surprising looking at the customers ratio evolution of the different suppliers that multipliers production and delivery to farmers is not rising when the demand is rising. This is due to the fact that the system has still not reach its full capacity (many farmers can work with SS obtained from DAO who obtained it easily from SC as its only concurrent which is AC is getting most of its provisions from its network as a pervert consequence of farmers adaptation) and that as multipliers production is driven by demand and demand is driven by suppliers reliability, AC and CSC never manage to increase significantly their customers numbers and indeed increase the number of seeds in the system by making new multiplications because their supply is not reliable enough (production hazards + completion by outside seeds) compared to DAO which is getting SS directly from DAO with a very high priority (figure 7).
The conclusion is that the hypotheses in the model allow representing faithfully a stable situation but are not good enough to represent a self adapting system.

3. DISCUSSION

3.1. Knowledge integration from various sources and at different scales

The multi level ABM implemented in this process makes use of indigenous as well as expert and scientific knowledge about the local RSS. It also represents interactions between the formal seed production and distribution system operated by public and private agencies, and the village and farm levels more informal practices regarding the use of rice seeds.

While the RPG was very useful to communicate the contents of a conceptual model, to enrich and validate it with its end users, the ABM allows to run simulations at the provincial scale with out being limited by either the number of participating players (which is always limited to less than twenty in a RPG session), or the cost (time and cash) of a simulation.

Potentially, there is no restriction on the number of stakeholders that can be simulated with the ABM. However we chose to use in the ABM the same simplified setting as in the RPG where only 4 sub-districts are represented (there are around 300 in a province) for several reasons : (1) it made it possible to design an interface very similar to the representations used during the gaming workshops that would hence look familiar to the stakeholders and would allowed to keep on deepening the discussions started during these workshops (2) it kept the simulation simple and allowed to easily check what is happening at the level of specific sub-districts (3) it creates a gap between real world data and simulation that prevent users to focus on results and figures instead of focusing on processes and hypotheses. This last reason was particularly important as we did not want our partners to confuse our simulator with a decision-support tool.

Used in the workshops, the model did reach its goal of extracting and confronting stakeholders information. It was particularly efficient in giving direct feedback on the hypotheses validated by the stakeholder in the form of histograms.

3.2. Limits and potential improvements of the ABM

From a more methodological point of view, modelling such a seed system leads to the representation of a very particular type of supply chain and so we could not find examples of simulations on which we could rely on in the operational systems literature :

- The production of certified seeds is a lengthy process while seed distribution occurs over a very short period of the year.

- Seed quality issues have to be taken into account during seed multiplication as seed quality is more important than seed price in the selection of a supplier by local farmers.
- Each stakeholder in the RSS thinks and acts at a very different scale.

The potential use of the simulator was as a tool for getting feedback on implications and potential unpredictable consequences of management options. The prototype that was developed in the time frame of the project only exhibits potential contributions of such a simulator. Developing this prototype into an operational tool would necessity a new round of interaction with stakeholders in order to identify focal aspects that should be deepened and collect further data and hypotheses. For instance the main limits are :

- the suppliers volume planning is only driven by the demand, may it be with perfect information (registered customers) or crude estimation on previous years. The consequence is that when farmers increase the demand on more reliable suppliers, the less reliable ones enter a positive feedback loop where they keep on reducing their volume planning as they keep on loosing customers. This is particularly true for seeds multipliers which volume planning is shifted by 1 year (time for producing the seeds). This results in a strong dependency to initial conditions (number of initial customers and initial score of a supplier) which does not look very realistic. It means that more information of main constraints and drivers of suppliers volume planning are needed.

- seeds producers cannot be as flexible as middlemen as they have constraints on the seeds production. At which rate are they able to increase or decrease their production capacity? Are there some upper and lower limits ? An important constraint on seeds producers dynamic that is not represented would be for instance the way contract farmers are contracted.

- farmers suppliers choice possibilities should not be homogeneous in a tambon. In reality they are driven strongly by accessibility to suppliers. It would be necessary to represent heterogeneities in terms of access to suppliers and information of the farmers.

- the simple situation should be upscaled to a situation with a number of stakeholders that would reflect the size orders of a province.

4. CONCLUSIONS AND PERSPECTIVES

The model presented in this paper was built in partnership with local researchers, representatives of local public and private seed producing organizations, as well as different types of rice growers in Ubon Ratchatani province. To our knowledge, there is no existing reference in the literature describing similar process and outputs.

The co-construction of the conceptual model and its use in role-playing games helped the stakeholders to understand the operation of the computer ABM used to simulate the RSS at a later stage. The acquisition of a more comprehensive perception of the provincial RSS triggered the identification of several relevant scenarios to be explored in order to anticipate the possible local consequences of the current reform of the RSS at the national level.

The potential and limits of the co-construction and dissemination of such a common model of the RSS among local actors was an important step to improve communication, build mutual understanding, facilitate information exchange, and promote coordinated action among them is discussed.

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Figure 1. Decision-making model for the choice of seed sources and suppliers at the farm level in Ubon Ratchathani, lower northeast Thailand.

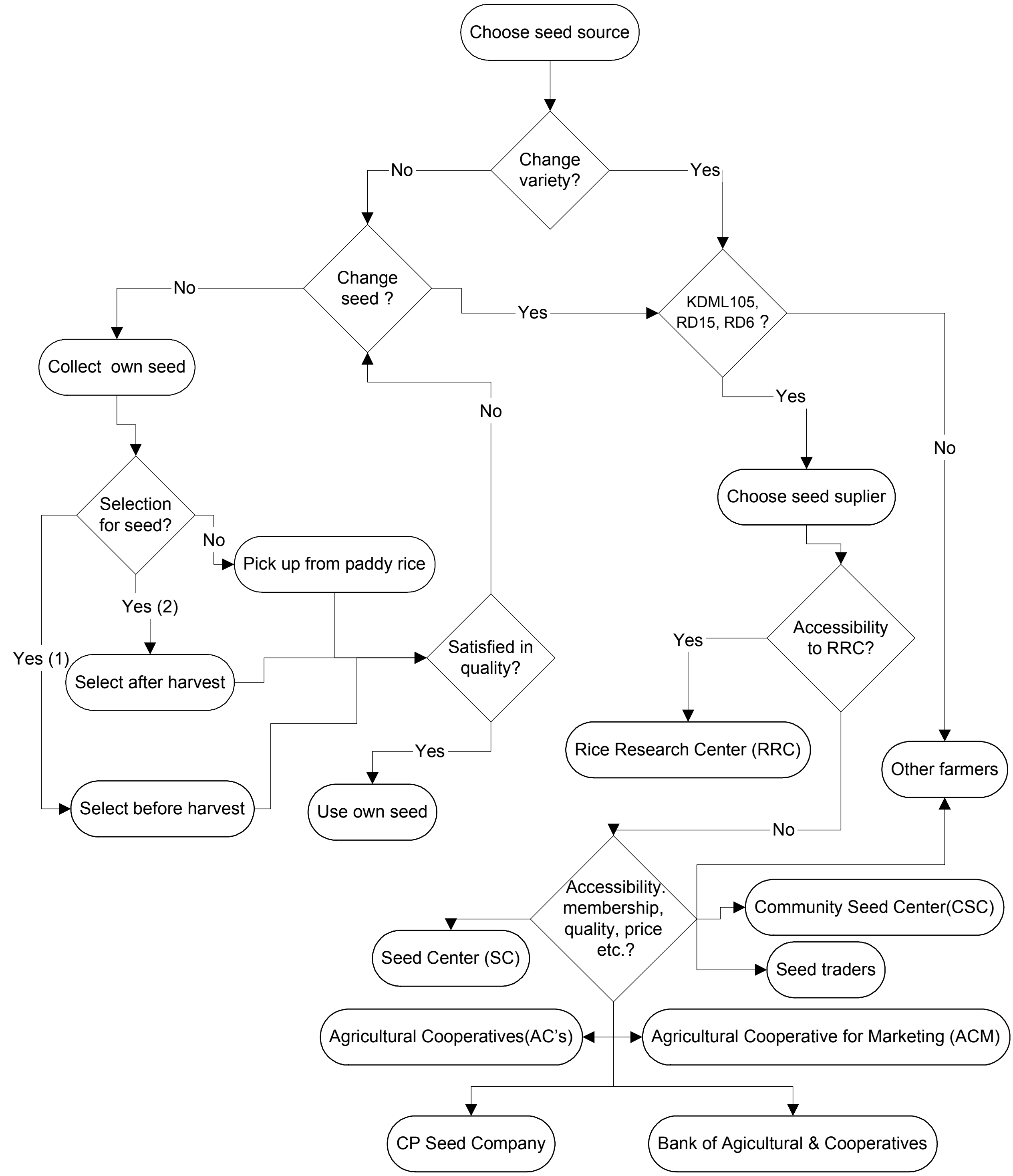

Choose seed source
Change variety?
No
Yes
Change seed ?
No
Yes
KDML105, RD15, RD6 ?
Collect own seed
No
Yes
No
Choose seed suplier
Selection for seed?
No
Pick up from paddy rice
Yes (2)
Accessibility to RRC?
Yes
Yes (1)
Select after harvest
Satisfied in quality?
Rice Research Center (RRC)
Yes
Other farmers
Select before harvest
Use own seed
No
Accessibility. membership, quality, price etc.?
Community Seed Center(CSC)
Seed Center (SC)
Seed traders
Agricultural Cooperatives(AC's)
Agricultural Cooperative for Marketing (ACM)
CP Seed Company
Bank of Agicultural & Cooperatives

Figure 2. The RLR seed supply system in Ubon Ratchathani, lower northeast Thailand.

NB: Seed flow among institutions deals mainly with KDML105, RD6, and RD15 recommended cultivars. Seed of other cultivars circulate through farmer-to-farmer exchanges only. Numbers below each agent indicate the number of locations or persons of each agent in Ubon Ratchathani province, except for Seed Center (SC) and CP seed company.

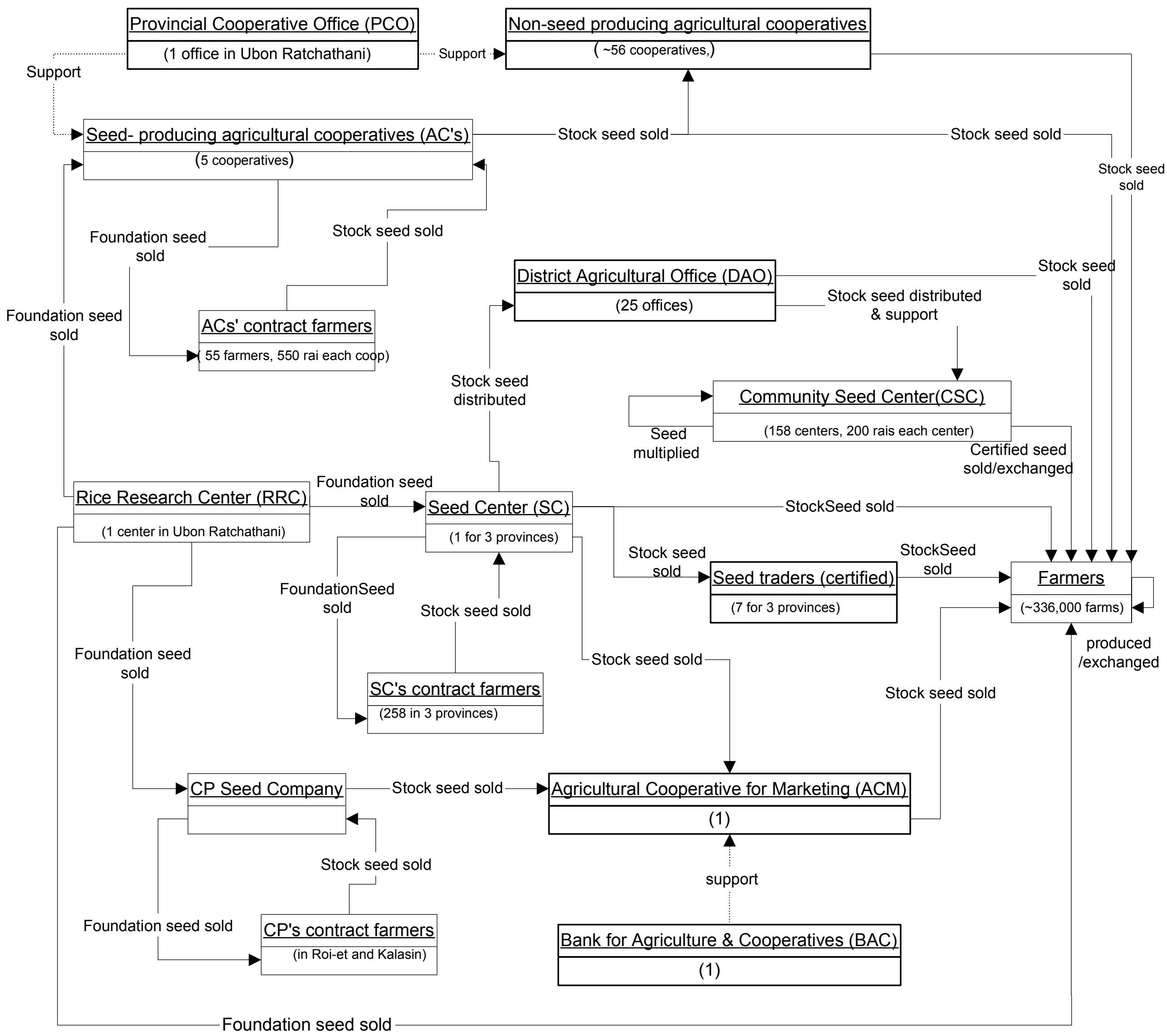
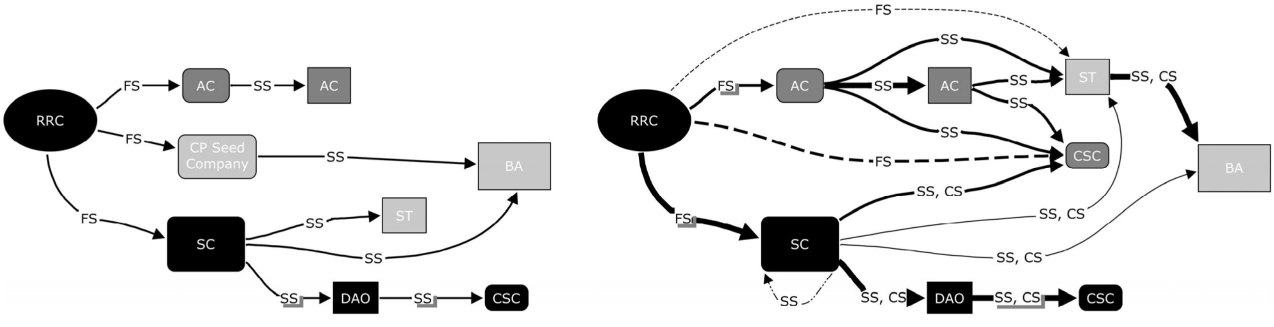


Figure 3 : seeds flow among RLR suppliers such as identified in the initial conceptual model and such as elicitated during the interactive workshops and implemented in the ABM



Links between the RLR system suppliers such as elicitated from the initial conceptual modelling phase

Links between the RLR system suppliers such as represented in the ABM

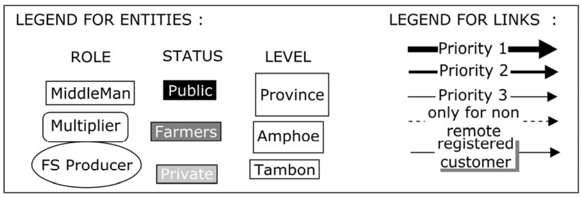


Figure 4 : ABM Interface showing customers priorities for SC

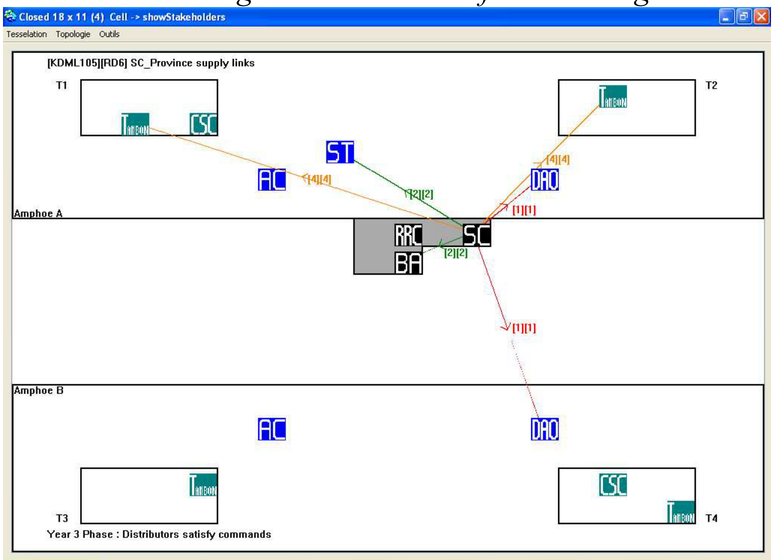


Figure 5 : ABM interface showing seeds flows during the different phases of a time step (left) and histograms showing results of decisions of a stakeholder

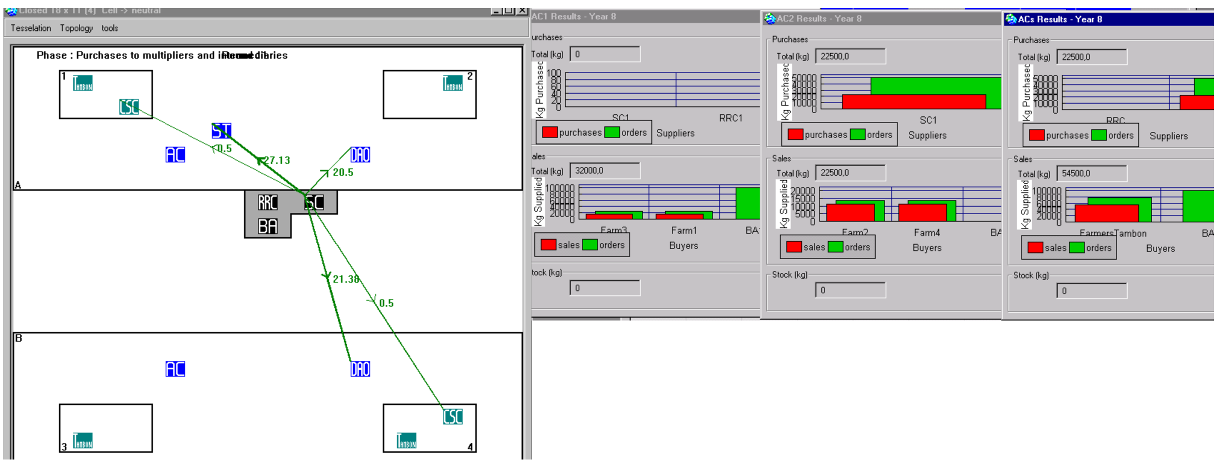
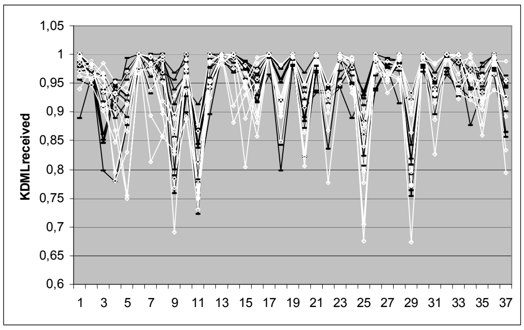
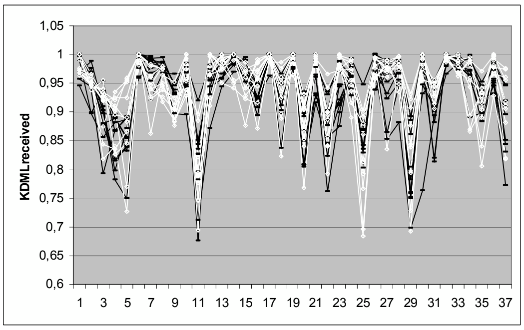


Figure 6: ratio of satisfied demands for KDML105 in baseline scenario, decentralisation scenario and modernisation scenario : in the baseline and decentralisation scenatios, the ratio of satisfied demands oscillates between 75% and 100 % when it is hardly not getting

below 90% in the modernisation scenario. Simulations where farmers do not change supplier are in black and those where they change are in white.





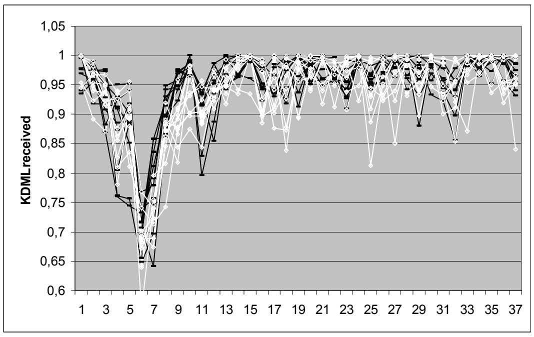
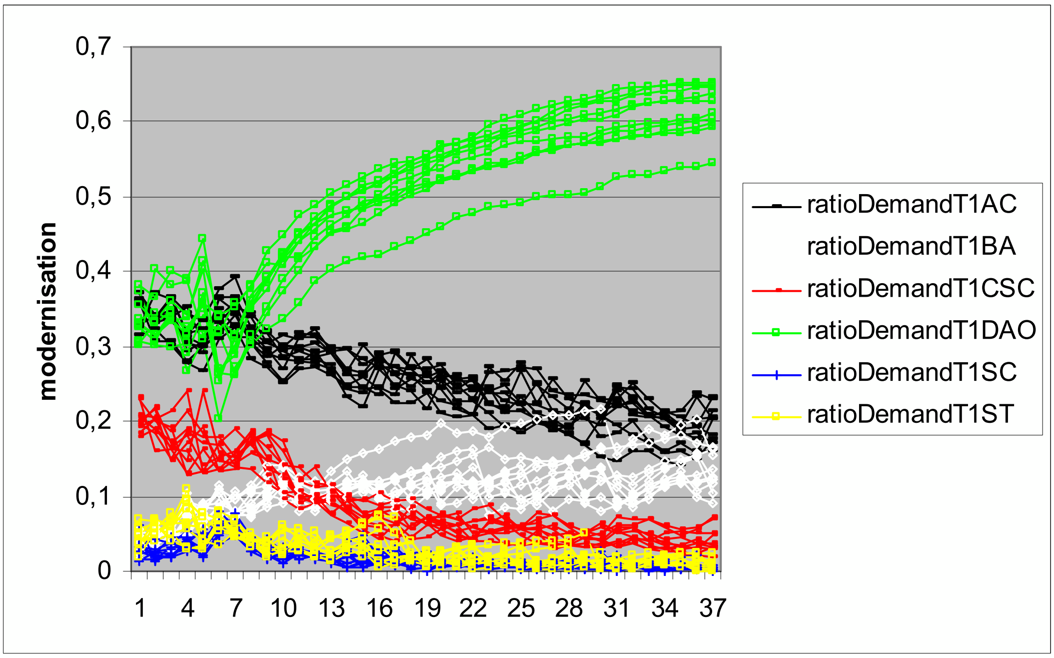


Figure 7 : ratio of customers from the different suppliers of tambon 1 in modernisation scenatio : the ratio of AC is getting up to 60 % and the ratio of CSC is getting down to 5 %



APPENDIX 1. DETAILS FROM THE MODEL – SUBMODELS

Paddy price evolution

It is drawn every year randomly between Market agent's marketUp and marketDown

paddyMarketPrice = Random (marketDown, marketUp)

Seeds production function

It consists in producing a quantity *Qdistrib* of FS and storing it in *FSProducer*'s *distributionStock*. *QPlanned* is the value decided by the planning function. The *hazard* is drawn from statistical field values (see initialisation tables). *QDistrib* is limited by the *FSProducer productionCapacity.*

Qdistrib = min(QPlanned(1+productionAlea), productionCapacity)*

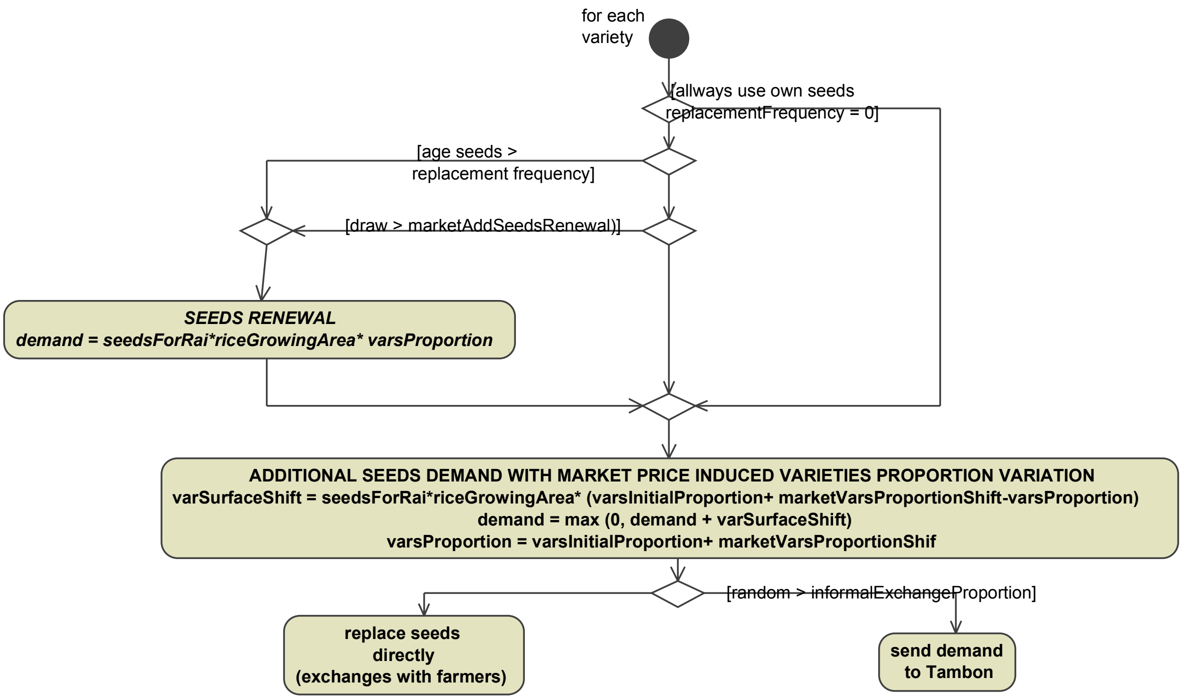
Seeds multiplication function

It consists in multiplying a quantity *QMult* of seeds into a quantity *Qdistrib* of the next generation seeds (FS into SS, SS into CS). *Qdistrib* is obtained through affecting the *Multiplier*'s *multiplicationRate* with an *hazard* drawn from statistical field values (see initialisation tables). The original seeds where stored in the *productionStock* and the multiplied seeds are stored in the *distributionStock.*

*Qdistrib = QMult * multiplicationRate* (1+ productionAlea)*

Farmers' seeds demand

The actual seed's demand submodel is described on the following activity diagram. There is an implicit hypothesis that if farmers decide to cultivate more surface of one variety because of market prices, they have to get additional seeds outside.



Seeds Supply planning

This function calculates *QPlanned,* the quantity a supply chain entity plans to provide during the year and aims at having in its distribution stock.

For **orders based planning**, with *ordersReceived* being the total of seeds orders received before planning and *margin* a security margin parameter :

QPlanned = (1+*margin*)**ordersReceived*

For **adjusted planning**, the entity computes the mean of requests received it can remember (*memory* parameter) and adds a security margin. Seeds producers divide by their multiplication rate. With *requestsReceived* being the total of seeds requests received during the previous year, *margin* the security margin parameter, *memory* the length of memory :

QPlanned(t)= (1 + *margin*) (*requestsReceived* (t-1) +.. + *requestsReceived* (t- *memory*)) / *memory*)

And for *SeedProducer* agents

QPlanned(t)= (1 + margin) (requestsReceived (t-1) +.. + requestsReceived (t- memory)) / memory * multiplicationRate)

Seeds Purchase
Multiplier and *MiddleMen* : providers priorities are fixed through the initialisation. 1st priority providers are asked first, and if several providers have same priority, one is randomly drawn. The provider is asked for the amount of seeds still needed to get to the planned quantity, is removed from the list, and its offer is automatically accepted. Requests are sent only to providers that still have seeds.
Special cases : SC and AC always fulfil their needs :
AC always get needed quantity of seeds from their network
SC complete its needed quantity of seeds with its own production

Seeds Distribution
If within a round, there is not enough seeds for all requested, a distribution function is built (and there will be no more seeds for next rounds!). The distribution function is built with the following constraints (discussed with stakeholders) :
If priority 1 buyers request lest than *70 mxDemand1* % of the stock, they get 100% of their demand and the remaining seeds are distributed to the others proportionally to their priority rank
Priority 1 buyers should always get at least *mnAnswer1* 60% of their request if there is enough seeds left for responding to *mnAnswerOthers* 10% of others' requests.
This means that with *requestsReceived(i)* being the total amount of seeds requested by a priority *i* buyer, *QDistrib* being the quantity of seeds available in the provider's *distributionStock,* and *QAnsw(i)* being the total amount of seeds returned to priority *i* buyers, then

$$QDistrib = \sum_i QAnsw(i) \text{ and } QAnsw(i) = wi * requests\mathrm{Re}ceived(i)$$

If $requests\mathrm{Re}ceived(1) < mxDemand1 * QDistrib$ then *w1=1*

If not then $w1 = \max\left(1, \dfrac{Qdistrib}{requests\mathrm{Re}ceived(1) + \dfrac{\text{mnAnswerOthers}}{\text{mnAnswer1}} * \sum_{i=2}^{iMax} requests\mathrm{Re}ceived(i)}\right)$

and in all cases $wi = \max\left(1, \dfrac{1}{i} * \dfrac{QDistrib - QAnsw(1)}{\sum_{j=2}^{jMax} \dfrac{requests\mathrm{Re}ceived(j)}{j}}\right)$ for *i>1*

It is possible that not all seeds are distributed if high priorities buyers ask for low quantities of seeds. In this case, iterations are done on remaining demands until all seeds are distributed.

Suppliers adaptation
We use gross hypotheses and make a simple disaggregation of suppliers choice so that we can make this choice dynamic without complexifying the model. These hypotheses are :

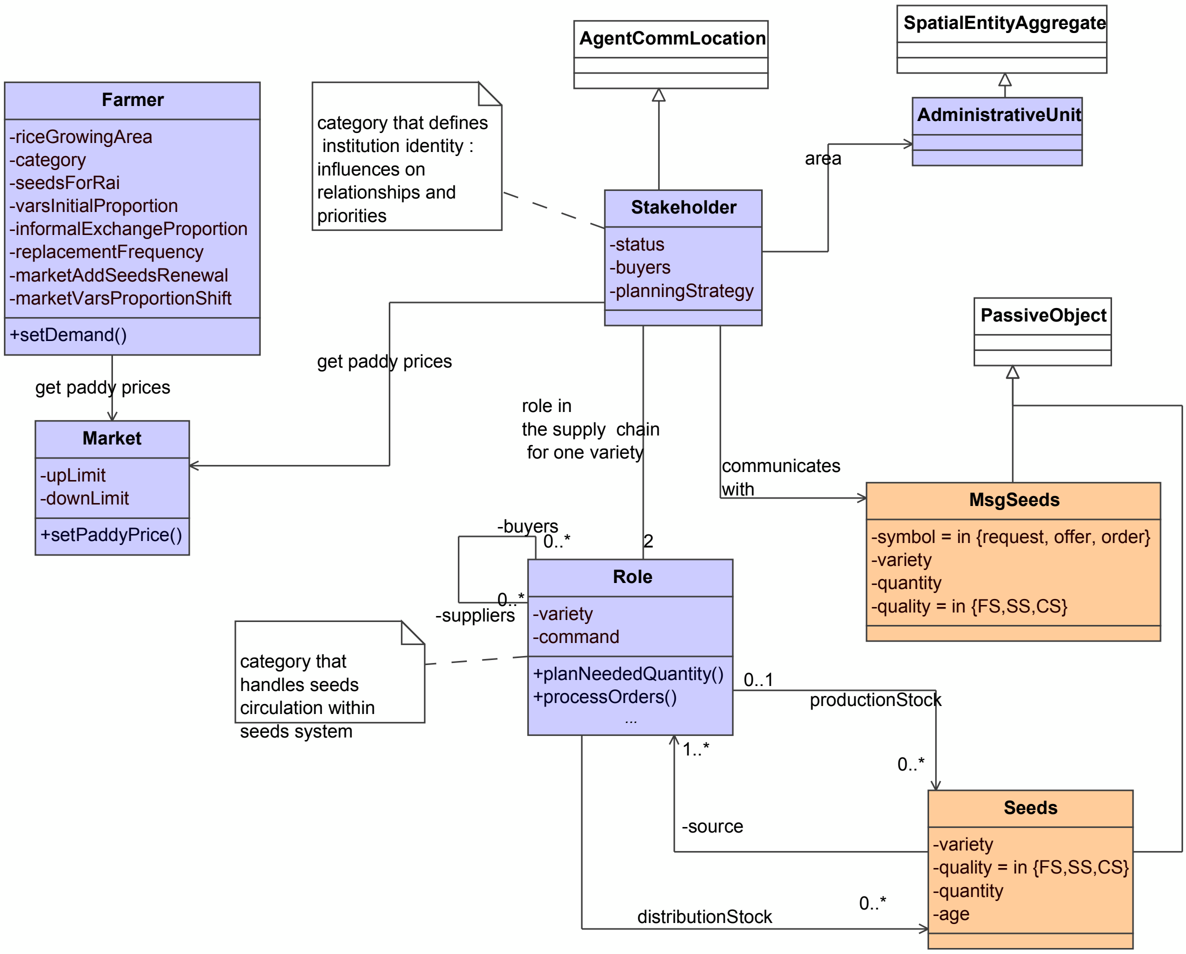
- all farmers in a tambon have an equal information and access to the suppliers in this tambon
- the accessibility to suppliers within a tambon is fixed during the time of the simulation
- each farmer has 1 supplier which is attributed initially from the statistics used currently in the aggregate demand
- each farmer has a unique supplier for RD6 and KDML during 1 year
- the seeds price has no impact on the supplier choice
- we do not consider loyalty or trust to suppliers : a farmer changes supplier when his demand is not satisfied or when he gets off-type seeds

- considering non adequate seeds (seeds that have been multiplied from CS or coming from outside the province through AC), there are 6 possibilities :
    - Changing and scoring -1
    - Changing and scoring 0
    - Changing and scoring 1
    - Not changing and scoring -1
    - Not changing and scoring 0
    - Not changing and scoring 1 (default)
- choice of a new supplier : each farmer which demand is not satisfied draws a new supplier in a collection where each supplier is represented his final scores times if > 1, once if not. This score can be established with 4 possibilities :
    - none (0)
    - based on reputation (1) : draw within tambon annual record of suppliers :
        - a supplier scores +1 when he satisfy 1 farmer demand
        - a supplier scores – 1 when he does not satisfy 1 farmer demand
    - based on experience (2) : draw within own record of suppliers :
        - a supplier scores +1 when he satisfy the farmer demand
        - a supplier scores – 1 when he does not satisfy the farmer demand
        - when its demand is not satisfied, the farmer draws a new supplier in a collection where each supplier is represented his current scores times if > 1, once if not
    - random (3)

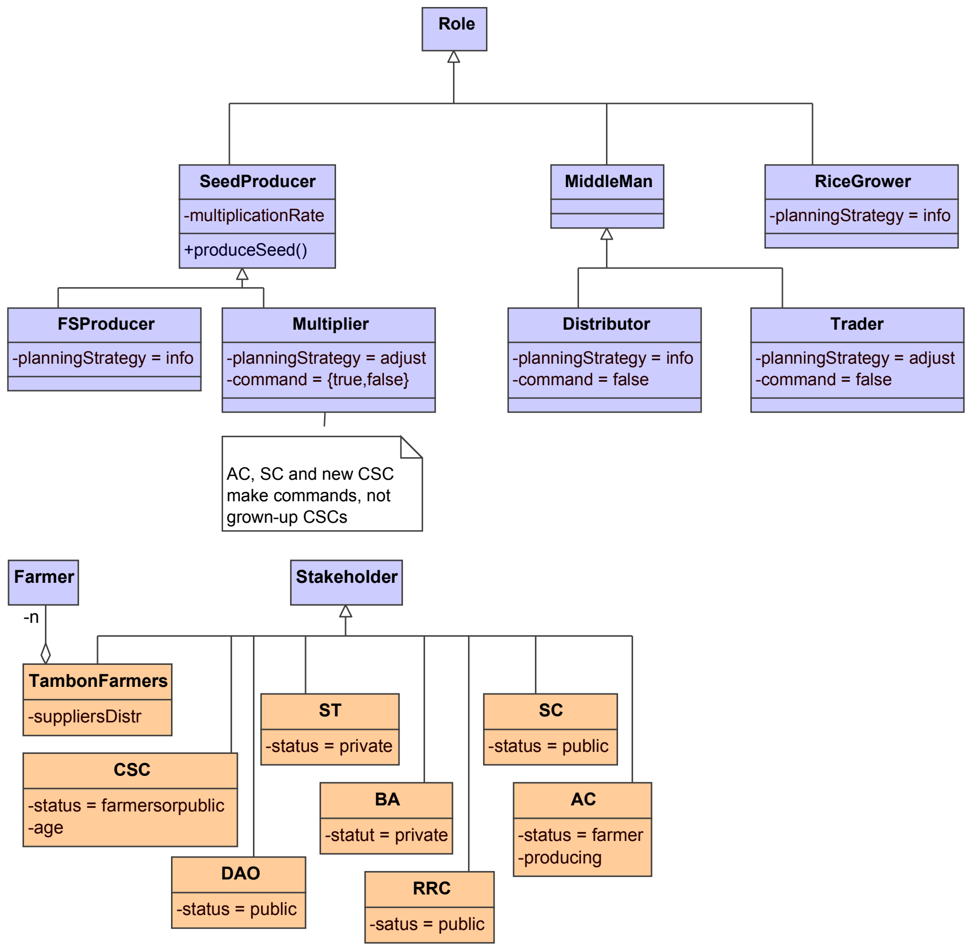
When farmer do not change supplier when they get off-type seeds but score them negatively, the results are stable but somehow locked for AC customers. As a consequence, it seems that the behaviour providing the more stability while providing some dynamics possibility is when farmers change suppliers when they get off-type seeds but score them positively (which means I try to find a new supplier because this one is not providing top quality but it is still ok because it has a reliable supply).

APPENDIX 2. DETAILS FROM THE MODEL – DIAGRAMS AND PARAMETERS

The class diagram shows how main classes are structured in the model.



These last 2 diagrams show stakeholders and roles hierarchies.



Units

The only quantity in the model is the quantity of resource : ton

Parameters table : Supply chain configuration parameters

These parameters are those who set the structure of the supply chain that was used and discussed during games and ABM sessions.

Name	Object	description	Phase(s) / submodel where used	Value / Value range	Origin	Comment (hypotheses or testing and calibration)
tambon	Cell	Parameters for model spatial configuration	0 – initialisation stakeholders	archetypal province with 2 amphoe containing 2 tambons each	Same as in RPG	2 Amphoes with 2 tambons each
amphoe	Cell					
province	Cell					
stakeholders	AdministrativeArea		0 – initialisation stakeholders	Tambon a1 : CSC1 Tambon b2 : CSC2 Amphoe a : AC1,	Same as in n RPG	For the province : RRC, SC, BA For each Amphoe : AC, DAO For non remote Amphoe : ST For 1 tambon in each Amphoe : CSC

				ST, DAO Amphoe b : AC2, DAO Province : RRC, SC, BA		
Accessibility	Amphoe	Accessibility of Amphoe	0 – supply chain config : CSC access to RRC & farmers access to SC in non remote only 1a – Farmers demand : informal seeds exchanges in remote only	a : normal b : remote	Just for having a differentiated situation	1 Amphoe remote, the other not
producing	AC	AC type	0a – supply chain links and priority initialisation 2 - production	true except for AC b KDML	Same as in RPG	
institutional Status	Stakeholder	Institutional status of stakeholder	0a – supply chain links and priority initialisation	RRC, SC, DAO, non grown up CSC : *publicOrganisation* AC, grownUpCSC : *farmersOrganisation* ST, BA : *privateOrganisation*	Discussed with stakeholders and experts	
Providers / customers	Role	Supply chain links	1b – Planning	* RRC supplies all SCs; producing ACs; non project CSCs and STs in non-remote amphoes. * SC supplies all DAOs, STs and BAs, non-project CSCs and non-producing ACs. * DAOs supply project CSCs in their amphoe. * All ACs supply STs and non-	First from RPG and refined during meetings using ABM	

				project CSCs in their amphoe. Producing ACs supply non-producing ACs in the province * BAs supply non-producing ACs; STs supply BAs * Farmers get seeds from any that serves their tambon except RRC and SC. Farmers in non-remote amphoe can buy to SC.		
customers (dict keys)	Role	Customers priorities= priorities used when treating requests		* RRC, SC : 1 for publicOrganisation; 2 for farmersOrganisation; 3 for privateOrganisation ; 4 for farmers * AC : 1 for others AC; 2 for others; 3 for farmers * others : 1 for all; 2 for farmers	Discussed with stakeholders	
providers (dict keys)	Role	providers priorities= priorities used when sending requests		same for everybody: RRC>SC>AC>BA,DAO,ST>CSC	Discussed with stakeholders	
distribution SessionsPopulation	Global	Population and scheduling of the distribution sessions within the time step	3 – distribution	1. RRC answers orders : customers = (AC, SC); providers = (RRC) 2. everybody but SC and RRC request seeds : customers = (AC, ST, DAO, CSC, BA); providers = (RRC, SC, AC, ST, BA)	Adapted from RPG with info from ABM sessions : ST may provide other providers; DAO may provide some CSC	Very sensible parameter Tested and calibrated

				3. DAO answers orders : customers = (TambonFarmers, CSC); providers = (DAO) 4. TambonFarmers receive seeds from everybody except DAO : customers = (TambonFarmers); providers = (AC, ST, CSC, BA, SC, RRC)		
nFarmers	Tambon	Number of farmers within a tambon	1b – farmers demand	1000	From RPG	

Parameters table : Other parameters

These parameters are the others parameters of the model.
Gray parameters are used for normalisation or fixed for our frame

Name	**Object**	**description**	**Phase(s) / submodel where used**	**Value / Value range**	**Origin**	**Comment (hypotheses or testing and calibration)**
marketUp	Market	Paddy market price up limit	1a – paddy price evolution	5500 bth/ton	Real market values – from experts	
marketDown	Market	Paddy market price down limit	1a – paddy price evolution	10000 bth/ton	Real market values – from experts	
marketPricesScenario	Market	Prestablished scenario for paddy prices	1a – paddy prices evolution	See after	For model analysis	Used as scenario for model analysis
riceGrowingAreaDistribution	Global	Table describing probability distribution used to draw farmers' rice growing area (1 rai < < 70 rai)	0 – Initialisation - farmers (and then impact on 1a-farmers demand)	See table 1	Survey data from 2002-3	Depends on amphoe accessibility To be tested in sensitivityanalysis
varsInitPropForRiceGrowingArea	Global	Table describing a farmer varieties initial proportion depending on his rice growing area	0 – Initialisation - farmers (and then impact on 1a-farmers demand)	See table 2	Survey data from 2002-3	To be tested in sensitivityanalysis
seedsReplacementFrequencyDistribution	Global	Table describing probability distribution used to draw farmers seeds replacement frequency (1< <5 or never)	0 – Initialisation - farmers (and then impact on 1a-farmers demand)	See table 3	Survey data from 2002-3	Depends on accessibility and variety **Modified in scenario ??** To be tested in sensitivityanalysis
informalExchangeProbability	Farmer	Probability that a farmer is getting new seeds through informal system	1a – Farmers demand	Non remote : 0 Remote : 20 for KDML; 30 for RD6	Survey data from 2002-3	Depends on accessibility and variety To be tested in sensitivityanalysis
marketBasedRenewal	Farmer	Probability that a farmer is renewing seeds before time depending on market paddy price	1a – Farmers demand	RD6 : 0 KDML : 0 if riceGrowingArea < 10; else 0 if paddyPrice < 8000; 30 if	From stakeholders	depends on rice growing area To be tested in sensitivityanalysis

				paddyPrice < 9000; 60 if paddyPrice < 9800; 100 if paddyPrice > 9800		
marketBasedVarsProportionShift	Farmer	additional kdml proportion depending on market paddy price	1a – Farmers demand	RD6 : 0 KDML : 0 if paddyPrice < 8000; 10 if paddyPrice < 9000; 15 if paddyPrice < 9800; 20 if paddyPrice > 9800		To be tested in sensitivityanalysis
offTypeScoring	Farmer	Scoring of supplier providing non tracable or non certified	4 – Assesment	-1; 0 or 1	Simplest set of hypotheses to generate farmers adaptation	Calibration : 1
off-type changing	Farmer	Decision of changing when getting non tracable or non certified	4 – Assesment	True / false	Simplest set of hypotheses to generate farmers adaptation	Calibration : true
adaptation	Farmer	Way the score is built to get a new supplier	4 – Assesment	None / reputation / experience	Simplest set of hypotheses to generate farmers adaptation	Calibration : none / experienfe
seedsForRai	Farmer	Quantity of seeds needed for 1 rai	1a – Farmers demand	0.005 t	From experts and stakeholders	
registeredCustomers	Role	Registered customers seeds requests are collected and used for seeds planning.	1b – Supply planning	SCs and producing ACs are registered customers for RRC ; project CSCs and Farmers are registered customers for DAOs.	Discussed (quite roughly) with stakeholders	
providersShares	Global	Tambons request seeds to providers according to these shares	1b – Supply planning 3 - distribution	T1 : ((CSC, 20%), (DAO, 35%), (AC, 35%), (ST, 5%), (SC, 2%), (BA, 3%)) T2 : ((DAO, 45%), (AC, 45%), (ST, 5%), (SC, 2%), (BA, 3%)) T3 : ((DAO, 48,5%), (AC, 48.5%), (BA, 3%)) T4 : ((CSC, 27%), (DAO, 35%), (AC, 35%), (BA, 3%))	Values from RPG	Fixed values..
planningStrategy	Stakeholder	Wether stakeholder use order based or adjusted planning	1b – Supply planning	SC, CSC, AC, ST, BA : adjusted RRC, DAO : orderBased	Discussed with stakeholders	
margin	Stakeholder	margin added on plannings	1b – Supply planning	RRC : 15 % Others : 0 %	Arbitrary	To Calibrate !!!
memory	Stakeholder	Number of years considered for planning adjustement	1b – Supply planning	All : 1	Arbitrary	To calibrate
multiplicationRate	SeedMultiplier	Seeds multiplication rate	1b – supply planning 2 – resource production	50	Discussed with stakeholder	Can be modified during simulation through interface
production Capacity	FSProducer	RRC production capacity	2 – resource production	1.75 ton for KDML, 0.4 ton for RD6	Scaled from real data (130 t / 30 t for 300	No calibration we consider it as a fixed constraint, scaled from reality.

					tambons)	
production Alea	SeedProducer	Alea on seed production and multiplication	2 – resource production	* RRC P(-25%) = P(+10%) = 1/16 P(-20%)=P(0)= 2/16 P(-15%) = P(-5%)=3/16 P(-10%)=1/4 * Others P(-50%) = P(+10%) = 1/16 P(-40%)=P(0)= 2/16 P(-30%) = P(-10%)=3/16 P(-20%)=1/4	From RPG (adapted from real data)	
mxDemand 1 mnAnswer1 mnAnswer Others	Role	Constraints for distributing seeds according to priority	3 – distribution	70 % 60% 10%	Discussed with stakeholders	

Annex tables

Table 1 : riceGrowingAreaDistribution is the probability distribution used to draw farmers' rice growing area

riceGrowingArea (raï)	Probability	
	Remote amphoes	Non-remote amphoes
0-9	16	15
10-19	36	42
20-29	22	17
30-39	14	15
40-49	4	9
50-59	5	2
>= 60	3	0

Table 2 : varsInitPropForRiceGrowingArea is the correspondence table between farmers' rice growing area and varieties intial proportion

riceGrowingArea (raï)	varieties *initialProportion*		
	RD6	Other Glutinous	KDML+RD15
0-9	53	18	29
10-19	35	18	47
20-29	35	15	50
30-39	32	12	56
40-49	24	9	67
50-59	25	14	60
>= 60	11	11	79

Table 3 : seedsReplacementFrequencyDistribution is the probability distribution used to draw farmers' seeds replacement frequency

replacementFrequency	KDML	RD6

(years)	Remote areas	Non-remote areas	Remote areas	Non-remote areas
1 to 2	43	21	12	19
2 to 3	27	50	38	48
3 to 4	15	8	29	19
4 to 5	5	5	9	0
never	10	16	12	14
Total	100	100	100	100